A Mechanical Attachment Designed for the Rapid Installation/Removal of Large TPS Panels on Cryotanks and Airframes

Airframe and cryotank skins would be supported by external stringers, to which insulating panels would be attached.

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Reducing the cost of delivering payloads to low Earth orbit (LEO) will expand the commercial space industry in this century in a manner similar to the expansion experienced by the commercial airline industry in the 20th century. Most of the payloads delivered to LEO today are transported by rockets, or expendable launch vehicles (ELVs), which are only used once. Common sense and economic studies suggest that reusable launch vehicles (RLVs) will eventually be more cost effective than single-use ELVs. Although the payload delivery cost of the world's first RLV, the space shuttle orbiter, exceeds the cost of current ELVs, the shuttle experience may be used to identify strategies for achieving significant cost reductions in the next generation of RLVs.

Developing new, low-cost, robust acreage thermal-protection systems (TPS) for reusable launch vehicles (RLVs) is critical to achieving a factor of 10 reduction in the payload delivery cost. Acreage TPS insulates the structure behind the nosecap and the wing leading edge on the space shuttle orbiter and represents 11 percent of the shuttle weight or 96 percent of the wetted surface area [~11,000 ft^2 (1,022 m^2)] on shuttle. In general, two acreage TPS systems were used on the shuttle. Rigid surface insulation (RSI) insulates the hot windward surface and flexible reusable surface insulation (FRSI) insulates the cooler leeward surface. Both insulators (RSI and FRSI) were directly bonded through strain isolation pads to an aluminum structure. Minimizing the weight of acreage TPS is very important because each pound of TPS displaces one pound of payload on every launch of the RLV. Furthermore, because the current labor cost required to maintain (inspect, repair, and refurbish) the acreage TPS for each launch is about the same as maintaining the space shuttle main engines (SSMEs), it is very important to develop new approaches to acreage TPS for achieving significant cost reductions.

Several important trends affecting the production and operations cost of reusable acreage TPS were explored in early shuttle design studies and now are useful in developing cost-reduction strategies. A step-wise approach to cost-reduction for acreage TPS involves the following steps: Step 1 represents the current shuttle baseline and Step 5 achieves a factor of 10 reduction in TPS operations cost. Currently, approximately 25,000 RSI panels [6 × 6 in. (15 × 15 cm) tiles] are directly bonded to the complex aerodynamically shaped windward surface of the shuttle. Both production and operations cost may be reduced by using carrier panels to increase the size of the RSI panels from 6 to 54 in. (15 to 137 cm) in Step 3. Further cost reduction is achieved in Step 4 by changing from a direct bond to a mechanical attachment. The final cost reduction in Step 5 is achieved by using much simpler vehicle geometries than the shuttle. Additional synergistic cost reductions are likely because the panels can be quickly removed for repair "off line" so as not to interfere with other maintenance operations.

An "Integrated Thermal Insulation System for Spacecraft" (U.S. Patent 5,803,406) was developed to implement the TPS configuration described in Step 5. Figure 1 depicts a simple example of a cryotank, or hypersonic airframe, with external stringers that stiffen the skin and provide mechanical attachments for large TPS panels. Thermal conduction through these external stringers, "or heat shorts," will increase propellant boiloff during launch, and may cause thermal degradation of the structure during reentry by overheating the skin. In a large slab of the insulating material under typical steady-state launch conditions, the temperature will decrease from 70 °F (21 °C) at the outer surface to about –300 °F (–184 °C) at the skin contacting the cryogenic propellants. Isotherms define locations inside the insulating slab with the same temperature and parallel the slab surfaces. Thermal conduction in the stringer may be minimized by locating the horizontal section (x) along an isotherm. As the length (x) is increased, the horizontal section becomes more isothermal and the temperature gradient (T/x) controlling thermal conduction is significantly reduced.

Maximum thermal conduction occurs in a stringer with a zero length ($x/L = 0$) that penetrates straight through the insulating slab. At the other extreme where the length (x) approaches infinity, no conduction occurs. The chart in Figure 1 shows that thermal conduction through a graphite composite stringer may be reduced by almost a factor of 5 when the horizontal section is located in the middle of the slab ($h/L = \Omega$) and its length equals the cryogenic insulation thickness ($x/L = 1$).

TPS panels protecting the cryogenic insulation and structural skin from reentry heating are attached to the top of the external stringers. In the simplest case, the TPS panel size matches the stringer spacing. Rigid or flexible TPS on these panels is directly bonded to a graphite composite structure with the "rapid release/attachment" fixtures shown in Figure 2. The joints (called "ruled joints") between adjacent panels would be defined by mating symmetrical, partial-quarter-round-edge cross sections. Rule joints are common in furniture with moveable sections, such as drop-leaf tables. The overlap of the rule joints would act to reduce the flow of hot gases through the joints and under the TPS panels. Precision overlapping rule joints may not require the gap-filler material utilized to plug gaps between the simple butt joints of a conventional tile installation on the space shuttle orbiter. The downstream installation sequence would eliminate forward-facing steps between the panels and thereby minimize premature tripping of the boundary layer from laminar to turbulent flow.

Panels would be installed in a downstream sequence (panel 1 followed by panel 2, panel 3 followed by panel 4). The upstream end of each panel would be equipped with pins that would engage keyhole-shaped slots in its upstream stringer. The pins would be inserted in the narrow parts of the slots, and the panel would then be hinged into initial approximate alignment. As the panel was lowered further into position, the pins would drop from the narrow parts of the slots into wider round holes, and tapers on the pins would mate with the edges of the round holes to ensure the correct alignment between the panel and the upstream stringer. Once the panel had been lowered into final position the pins interlock the panels 3 and 4 to their common stringer. At the opposite end of panel 4, two lockdown bolts are installed to securely attach it to the downstream stringer. After a flight, the panels may be removed by reversing the procedure and an identical set of replacement panels from the spares inventory may be immediately installed. The turnaround time to refurbish the RLV is significantly reduced because inspection, repair, and refurbishment of the removed TPS panels may be completed off-line without constraining other maintenance activities.

This work was done by Paul Kolodziej and Jeff Bull of **Ames Research Center** *and Tom Kowalski and Matt Switzer of Eloret. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 20]. Refer to ARC-14052.

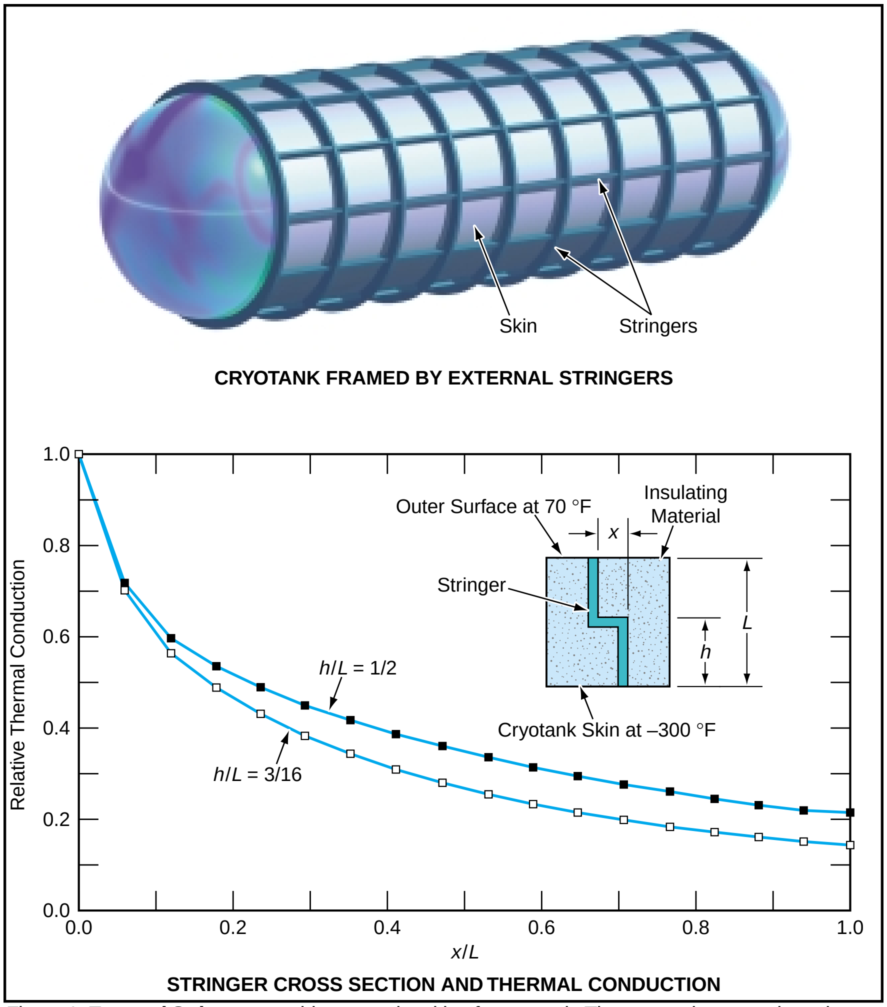

Figure 1. **External Stringers** would support the skin of a cryotank. The spaces between the stringers would be filled with an insulating material. The graph shows the thermal conduction through a stringer with a chair cross section for given values of x and h, divided by the thermal conduction through a simple straight stringer ($x = 0$). The values of thermal conduction were calculated for a stringer material with a thermal conductivity of about 7.4×10^{-6} Btu/(in.·s·°F) [0.55 W/(m·K)], an insulating material with a thermal conductivity of about 7.2×10^{-7} Btu/(in.·s·°F) [0.054 W/(m·K)], and a total thickness (L) of 2-1/8 in. (5.40 cm).

Figure captions:

Step Panel Size, in Normalized

Panel Size Attachment

Technique Panel

Geometry Normalized Production Cost Normalized Operations Cost 1 6 Shuttle

Direct

Bond Complex 100% 100% 2 20 Medium Direct

Bond Complex 45% 91% 3 54 Large Direct

Bond Complex 24% 57% 4 54 Large Mechanical Complex 24% 11% 5 54 Large

Mechanical Simple 17% 8%

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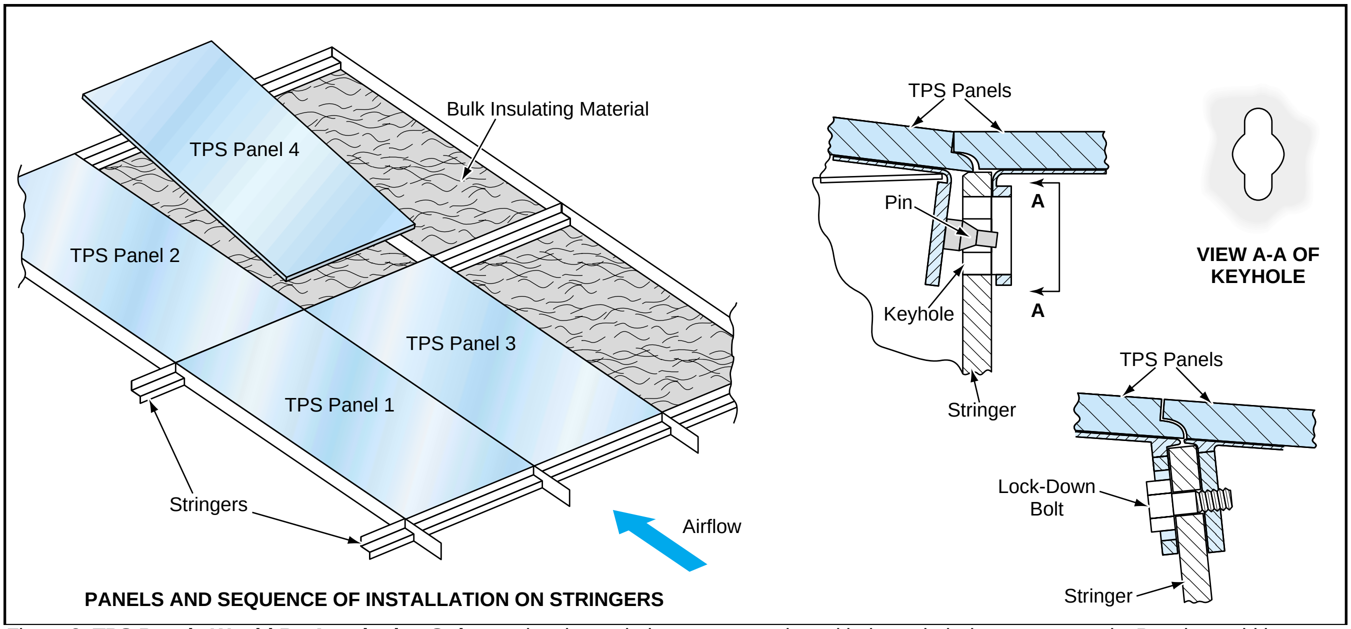

Figure 2. **TPS Panels Would Be Attached to Stringers** by pins at their upstream ends and bolts at their downstream ends. Panels would be installed in a downstream sequence and removed in an upstream sequence. Installation and removal could be accomplished quickly and easily.